Effects of Routine Late-Season Field Operations on Numbers of Boll Weevils (Coleoptera: Curculionidae) Captured in Large-Capacity Pheromone Traps

ALLAN T. SHOWLER[1]

USDA–ARS SARC, 2413 East Highway 83, Weslaco, TX 78596

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ABSTRACT Flat and cylindrical adhesive boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae), pheromone traps captured significantly more ($P \leq 0.05$) boll weevils than the Hercon (Hercon Environmental, Emigsville, PA) trap during the late cotton-growing season, and larger adhesive areas were associated with higher captures; a flat plywood board collected the most boll weevils because it had the largest surface area. The flat board trap, chosen for measuring large late-season adult boll weevil populations common to the Lower Rio Grande Valley of Texas in 2000 and 2001, collected more ($P \leq 0.05$) weevils when deployed in proximity to natural and cultivated perennial vegetation, and mean numbers of captured boll weevils were higher ($P \leq 0.0001$) on the leeward sides of the board traps than on the windward sides. The board trap had an estimated potential capacity of ≈27,800 boll weevils, and the large capacity of the board trap allowed for more accurate measurements of large adult boll weevil populations than the more limited Hercon trap. Measurement of adult boll weevil numbers after the routine field operations of defoliation, harvest, shredding, and stalk-pulling, demonstrated that large populations of boll weevils persist in cotton fields even after the cotton crop has been destroyed. Increases ($P \leq 0.05$) in the percentage variation of trapped boll weevils relative to the numbers collected just before each field operation were observed after defoliation, harvest, shredding, and stalk-pulling, but the percentage variations followed a quadratic pattern with significant correlation ($P < 0.0001$; $0.59 <$ adjusted $r^2 < 0.73$). Numbers of adult boll weevils caught on board traps deployed at 15.24-m intervals on windward and leeward edges of cotton fields suggested that boll weevil populations in flight after field disturbances might be affected by large-capacity trapping.

KEY WORDS boll weevil, *Anthonomus grandis*, cotton, trapping

THE BOLL WEEVIL, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae) was first reported in the United States near Brownsville, TX in 1894 and it has since spread throughout the southern Cotton Belt (Rummel and Summy 1997). Various types of boll weevil traps have been compared (Hardee et al. 1996) for monitoring the presence of populations (Merkl et al. 1978) and for collecting specimens (Leggett et al. 1975, Leggett 1979). Hardee et al. (1971) provided evidence that pheromone traps suppressed >80% of boll weevil populations in parts of west Texas. Boyd et al. (1973) conducted a large-scale field trial by using an aldicarb bait and found 90.6% fewer boll weevil punctured squares and 77.3% fewer adult boll weevils than when the traps were not deployed, but cotton yield data were not reported. Bait sticks for boll weevil suppression rely on the attractancy of grandlure to bring boll weevils in contact with a tube or stick containing an insecticide; the weevils presumably die from toxic exposure after leaving the stick (Villavaso et al. 1998). The efficacy of bait sticks, however, is unclear; some studies report successes (Daxl et al. 1995, Langston 1996) and others document failures (Fuchs and Minzenmayer 1992, Karner and Goodson 1993). Spurgeon et al. (1998) found that bait sticks killed 2.2% or fewer of the boll weevils that encountered the stick. Villavaso et al. (1998) found that bait sticks with adhesive were more effective at removing boll weevils from fields than other trap types.

Low winter temperatures in most of the boll weevil's distribution in the United States cause mortality in overwintering populations (Stone et al. 1990, Parajulee et al. 1996) and this mortality has assisted control programs to eradicate or suppress boll weevil infestations (Smith 1998). The Texas Lower Rio Grande Valley, however, is a unique subtropical region of the United States that supports active, breeding boll weevil populations year round (Guerra et al. 1982, Summy et al. 1988) despite mandatory cotton stalk destruction before 1 September and prohibition on planting until 1 February (Texas Department of Agriculture 1998). During the Lower Rio Grande Val-

[1] E-mail: ashowler@weslaco.ars.usda.gov

ley cotton growing season, principal commercial practices for reducing boll weevil populations rely on insecticide applications. Boll weevils in Texas can be trapped, using pheromone lures, in the largest numbers during the late season after boll weevil populations have built up throughout the cotton growing season, and when cotton, the preferred host, is being systematically destroyed late in the season as part of harvest and postharvest operations (Beerwinkle et al. 1996, Parajulee and Slosser 2001). The main objectives of this study were 1) to improve upon trap designs for measuring large adult boll weevil populations, and 2) to show the effects of various routine late-season cotton field operations on boll weevil trap captures.

Materials and Methods

Trap Design Comparisons. Two trap designs were developed in the laboratory at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center in Hidalgo County, TX, and the efficiencies of the new trap designs were compared with that of the commercially available Hercon Scout trap (Hercon Environmental, Emigsville, PA). The Hercon trap with a 10-mg Hercon pheromone lure collects living boll weevils in an 85-ml ventilated plastic cap after they pass through an inverted wire mesh cone designed to minimize escapes.

One of the two new trap designs consisted of 91.5 cm lengths of cylindrical polyvinylchloride trap pipe capped on one end and placed over a narrower 61-cm-long polyvinylchloride support pipe driven 15 cm into the soil (Fig. 1A). The outer surface of the trap pipe was coated with a 1–2-mm-thick layer of adhesive Tropical Formula Tanglefoot (The Tanglefoot Company, Grand Rapids, MI). A 10-mg Hercon pheromone lure was held by a metal clip fastened to the top of the pipe's cap. Four pipe diameters (cm):surface areas (cm^2) were tested: 2.5:730, 3.8:1,095, 5.1:1,460, and 7.6:2,189, hereafter referred to by their diameters.

The other trap design was comprised of 8-mm-thick plywood with 5,563 cm^2 of surface area that received a 1–2-mm-thick layer of adhesive, and the pheromone lure was held by a clip at the top of one of the trap's wooden supports (Fig. 1B). Both traps were spray painted fluorescent yellow (ACE Hardware, Oak Brook, IL).

In 1999, the six different traps (four pipe diameters, the board, and the Hercon trap) were deployed 61 m apart along the windward edges of each of five cotton fields in Cameron County, TX. The positions of the trap designs were rerandomized on each trap line every week to minimize potential position effects. Boll weevil captures were recorded weekly from each of the five sets of traps during the early and mid-cotton-growing season from 26 February to 11 June, and during the late season from 12 July to 9 August.

In 2000, eight separate trap lines in Hidalgo County, TX, ≈35 km from the 1999 study site, were each comprised of a Hercon trap, a 3.8-cm and a 7.6-cm pipe trap, and a board trap spaced 61 m apart. The two pipe trap diameters were selected because they differed from one another by 2×, and because the 1999 component of the study indicated that the two diameters were sufficient for making comparisons against the Hercon and board traps rather than using all four pipe diameters again. Captured boll weevils were counted every 48 h, 9–24 August. The traps were moved within each trap line every 48 h so each different trap design was sited at every position in each of two 8-d periods. Cumulative trap line data for each year were analyzed using three-way analysis of variance (ANOVA) and a split plot design with locations (whole-plots), dates (sub-plots), and traps as sources of variation. Tukey's multiple range test was used to separate the means of the trap designs whenever significant F values ($P \leq 0.05$) were detected (Analytical Software 1998).

The Hercon trap and the board trap, each with a 10-mg pheromone lure, were compared in a controlled environment by placing each in separate 1.5 by 2.5 by 2.5-m (w × l × h) cages in the laboratory. Fifty randomly selected boll weevils (sex ratios not determined) were released in each cage and trap captures were recorded every 10 min until 25 boll weevils were collected in one of the two traps. Then the boll weevils were all removed from the traps and cages and the process was repeated ($n = 15$). Repeated measures analysis was run to assess the effects of trap type and time on the numbers of boll weevils captured up until 2.5 h after the weevils were released in the cages (in some replications of the board trap, all 25 weevils were captured by 160 min). Numbers of boll weevils were $\log(x + 1)$ transformed before repeated measures analyses, and linear regressions were run on each set of trap data (Analytical Software 1998).

Effects of Orientation on Efficiency of Board Trap. During 2000, one board trap was placed midway on each of the four sides of 12 commercial cotton fields (each ≥20 ha in area) in Hidalgo County. The flat surface of each board was parallel to the adjacent field margin. Boll weevil captures were recorded every 48 h, from 9 August to 2 September. Effects of board orientation to wind direction on the efficiency of boll weevil capture was determined by comparing the numbers of captured boll weevils every 48 h on boards perpendicular ($n = 24$) and parallel ($n = 24$) to the southerly wind. On the 24 boards that were perpendicular to the wind direction, captures on the windward and leeward sides were recorded every 48 h. Influence of proximate (≤5 m) brush (brush was mostly comprised of huisache, *Acacia farnesiana* (L.) Willd.; mesquite, *Prosopis glandulosa* Torrey; retama, *Parkinsonia aculeata* L.; Texas ebony, *Pithecellobium ebano* (Berlandier) C. H. Muller; and desert hackberry, *Celtis pallida* Torrey) lines was assessed by comparing the numbers of boll weevils captured every 48 h on 26 traps along brush lines, and numbers of boll weevils captured on 22 traps more distant (≥25 m) from brush lines. Of the 26 proximate traps, only one was leeward of the brush line. Significant differences between the two treatments of each board orientation assay were detected using the two-sample t-test (Analytical Software 1998).

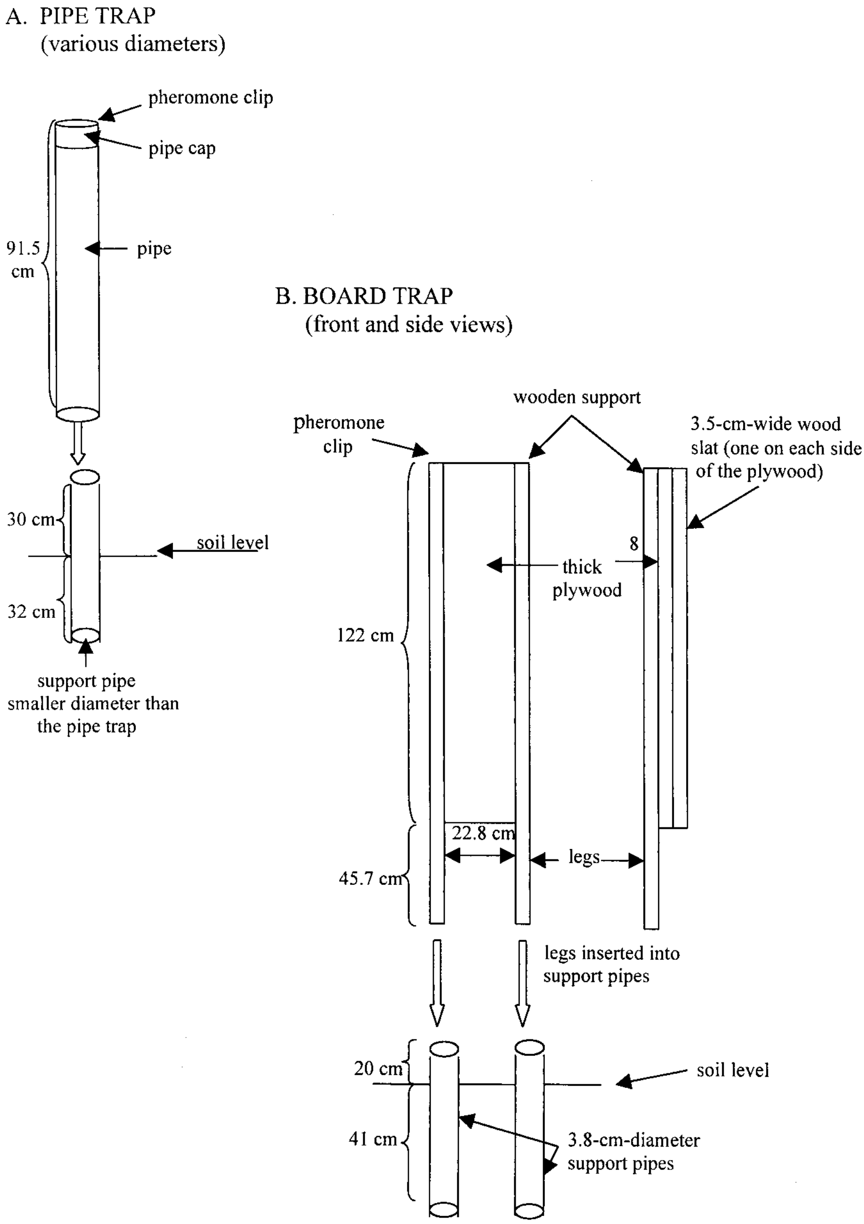

Fig. 1. Diagrams of pipe (A) and board (B) traps. The board's wood slats and legs were not coated with adhesive so that the traps could be slid on and off of racks on a custom built board trap trailer.

Effects of Routine Late-Season Field Operations on Trap Captures. In mid-June 2000 and 2001, one board trap was placed midway on the windward sides and one midway on the leeward sides of six commercial cotton fields in southern Hidalgo County, and six commercial cotton fields in northern Hidalgo County. All fields were ≥20 ha in area. The flat surface of each board was parallel to the adjacent field margin. The sets of six fields used in northern and southern Hidalgo County were located within the same 20 km^2 area in both 2000 and 2001. Boll weevil captures were recorded 4 d before the application of defoliant and every 48 h thereafter until 3 wk after stalk-pulling.

All fields were defoliated with s,s,s-tributylphosphorotrithioate on 26–27 June 2000 and on 7–8 July 2001 in southern Hidalgo County, and on 7–8 July 2000 and 9–10 July 2001 in northern Hidalgo County. Harvest was conducted using six-row mechanical combines on 3–5 July 2000 and on 3–4 August 2001 in southern Hidalgo County, and on 20–22 July 2000 and on 23–24 July 2001 in northern Hidalgo County. Shredding, using a six-row flail shredder, was con-

Table 1. Mean numbers of boll weevils (± SE) captured in six traps during early and late season (Hidalgo County, TX, 1999 and 2000)

Season (population level)[b]	No. boll weevils collected/48 h[a]					
	Hercon trap	2.5-cm pipe	3.8-cm pipe	5.1-cm pipe	7.6-cm pipe	Board
Early (low) 1999	2.2 ± 0.4a	1.5 ± 0.3a	1.1 ± 0.25a	1.1 ± 0.2a	2.0 ± 0.5a	1.5 ± 0.4a
Late (high) 1999	128.5 ± 30.6c	364.7 ± 63.0bc	604.8 ± 119.8b	552.8 ± 97.9bc	700.8 ± 118.9b	1,184.8 ± 213.8a
Late (high) 2000	176.8 ± 29.2c		872.4 ± 167.8bc		1,735.1 ± 290.9b	3,417.5 ± 599.7a

[a] Means within rows followed by different letters are significantly different ($P \leq 0.05$), Tukey test.
[b] Low, 1.22 ± 0.17 boll weevils per week based on board trap captures, 26 February–11 June; high, 1,184.8 ± 213.0 boll weevils per week based on board trap captures, 12 July–9 August 1999.

ducted on 14–15 July in southern Hidalgo County and on 21–22 July in northern Hidalgo County during 2000. In 2001, shredding occurred within 24 h of harvest in all of the fields. In southern Hidalgo County, stalk-pulling, using a 6-row custom built stalk puller, occurred on 14–16 July and on 12–13 August in 2000 and 2001, respectively. Stalk-pulling was conducted in northern Hidalgo County on 10–11 August and on 31 July–1 August in 2000 and 2001, respectively. When average trap captures declined to <100 boll weevils per 2 d or average trap captures were in decline for at least two sampling intervals, the farmer conducted another field operation except during 2001 when competing operational priorities for some of the cooperating growers resulted in the need to shred within 24 h of harvest. During 2001, the combination of harvest and shredding was considered as being one operation.

The two samples before defoliant application represented an initial baseline rate of capture, so they were averaged for comparisons with subsequent samples using the Dunnett test (SAS Institute 1998). Data for the four combination of northern or southern Hidalgo County and year were analyzed and presented separately. Repeated measures analysis was run using PROC MIXED (because of missing data points) (SAS Institute 1998) to assess the effects of field operations and time on the numbers of boll weevils captured. Numbers of boll weevils were $\log(x + 1)$-transformed before repeated measures analyses (Analytical Software 1998); however, untransformed means are presented.

Percentage differences were calculated between the number of trapped boll weevils immediately before each field operation and the numbers collected at each sampling time afterward until the next field operation, or, after stalk-pulling (the last operation) until numbers of boll weevils had declined to levels comparable to other preoperation baseline counts. All percentages were arcsine-square root transformed before analyses. Quadratic regressions were run on each field operation subset of transformed percentages (SPSS 2000). Ninety-five percent confidence intervals were used to detect significant differences in the numbers of trapped boll weevils between sampling times. The regression coefficients of each type of field operation were analyzed for possible differences by calculation of confidence intervals.

Multiple Board Field Test. Ten board traps were placed 15.24 m apart along each leeward and windward edge of five northern Hidalgo County cotton fields, all >20 ha, on 3 July 2001. The two sets of 10 traps in each field were deployed directly opposite one another (≥120 m apart). A single board trap was placed 250 m away from the nearest of the sets of 10 boards along the windward and leeward edges of the same five cotton fields. Defoliant application, harvest-shredding, and stalk-pulling occurred on 8–10, 22–23, and 29–30 July 2001, respectively. Numbers of boll weevils on the middle two boards in each set of 10 boards (the subsets of four boards per field are henceforth referred to as "multiple pairs" of traps) were counted every 48 h after the traps were deployed. Numbers of boll weevils captured on the single pairs of boards 250 m away from the sets of 10 boards (henceforth referred to as "single pairs" of traps) were counted at the same times as the multiple pairs. Counts were continued for 3 wk after stalk-pulling. Repeated measures analysis was run to assess the effects of multiple versus single pairs of boards and time on the numbers of captured boll weevils. Numbers of boll weevils captured on the multiple boards were halved for making direct comparisons to the numbers counted on the single-pairs and then numbers of boll weevils were $\log(x + 1)$ transformed before repeated measures analysis (Analytical Software 1998); however, untransformed means are presented. Data for each peak associated with a field operation also were analyzed using repeated measures. Each field operation-associated boll weevil capture peak was analyzed using quadratic regression (SPSS 2000). One-way ANOVA was run to detect significant differences between the three operations-associated peaks within each treatment (multiple- versus single-pairs), and means were separated using Tukey's multiple range test. The slopes of each type of field operation were analyzed for possible differences by determination of 95% confidence intervals. Comparisons between mean numbers of boll weevils collected during all 34 d of the study were made using the two sample t-test ($n = 5$) (Analytical Software 1998).

Results

Trap Comparisons. When boll weevil populations were uniformly low (<10/trap/wk), 26 February–10 June, no significant differences were detected among the six different traps (Table 1). At late season population levels, 12–16 July, the board trap caught ≈9 times more boll weevils than the Hercon trap. The pipe trap captures were not significantly different

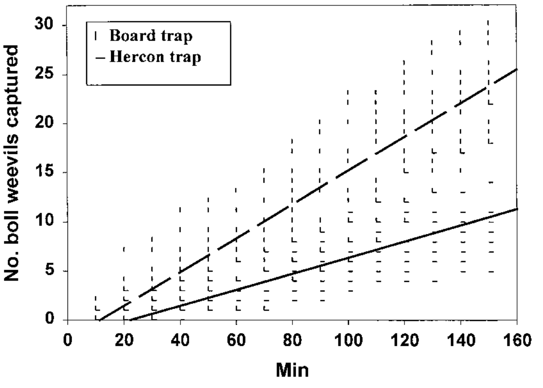

Fig. 2. Lines of best fit for numbers of adult boll weevils collected by board and Hercon traps at 10-min intervals in cages for 150 min, each with 50 boll weevils ($n = 15$).

from one another, but the pipe traps captured significantly fewer boll weevils than the board trap. Interaction ($P = 0.0005$) between trap and sampling date factors was detected. During the late season, 30% of the Hercon traps collected no boll weevils when the minimum corresponding board capture was 82 and the highest was 511. On one occasion, the Hercon trap collected two boll weevils compared with to 447 caught on the 2.5-cm pipe trap and 2,228 on the board trap.

Board traps caught significantly more boll weevils than Hercon traps in 2000 (Table 1). The 7.6-cm pipe caught twice the number of boll weevils collected on the 3.8-cm pipe. The board had ≈5 times more adhesive surface area than the 3.8-cm pipe, and the board caught ≈4 times more boll weevils.

Repeated measures analysis of the trap data indicated a significant trap effect ($F = 400.5$, df = 1, 420, $P < 0.0001$), time effect ($F = 82.64$, df = 14, 420, $P < 0.0001$), and interaction between treatment and time effects ($F = 7.91$, df = 14, 420, $P < 0.0001$). Mean numbers of captured boll weevils in each trap type increased over time, but board captures occurred at a greater linear rate (slope = 0.172, $t = 30.33$, $P < 0.0001$) than Hercon captures (slope = 0.082, $t = 22.58$, $P < 0.0001$) (Fig. 2). The board trap captured 20 of the 50 boll weevils in each cage in 121.2 ± 4.3 min. During the same time, the Hercon trap caught 55% fewer ($t = 10.84$, df = 1, 28, $P < 0.0001$) boll weevils.

Effects of Orientation on Efficiency of Board Trap. The boards caught ≈21% more boll weevils when perpendicular to the wind direction than boards parallel to the wind direction, but the difference was not statistically significant ($P \geq 0.05$) (Table 2). The leeward sides of the boards caught 2.one-fold more ($t = 6.96$, df = 1,23, $P \leq 0.0001$) boll weevils than the windward sides. Board traps proximate to brush lines caught 1.5 times more boll weevils than traps more distant from brush lines ($t = 2.82$, df = 1,21, $P = 0.0103$).

Effects of Routine Late-Season Field Operations on Trap Captures. Repeated measures analyses of boll weevil trap captures in each of the two sampling areas in each year throughout the sampling periods shown (Fig. 3) detected significant treatment (field operation) (2000; $F \geq 5.09$, df = 3,20, $P \leq 0.009$; 2001; $F \geq 12.99$, df = 2,15, $P \leq 0.0005$) and time effects (2000; $F \geq 24.85$, df = 6,75, $P < 0.0001$; 2001; $F \geq 10.09$, df = 6,70, $P < 0.0001$), and treatment*time interactions (2000; $F \geq 14.82$, df = 8,75, $P \leq 0.0004$; 2001; $F \geq 7.53$, df = 8,70, $P < 0.0001$). The line of best fit for the data after each field operation was quadratic, and followed the model $y = a + b_1{*}time + b_2{*}time^2$ where a is the intercept and b_1 and b_2 are the coefficients for the linear and quadratic terms, respectively. The average r^2 (i.e., the explained variance) of the data to the line of best fit for field operations was 0.662 ± 0.039. In both northern and southern Hidalgo County, 2000 and 2001, boll weevil captures increased after defoliant application, but the increases appeared to be relatively gradual (Fig. 3) and capture peaks did not occur until after 8–10 d compared with the other peaks (associated with harvest, shredding, harvest and shredding, and stalk-pulling) which occurred within 2–4 d after each field disturbance ($P \leq 0.05$). Also, mean percentage increases in numbers of trapped boll weevils were significantly higher ($P \leq 0.05$) in contrast to the baseline sample taken immediately before each field operation.

Table 2. Effects of orientation of traps to wind and brush on mean (± SE) numbers of boll weevils captured on board traps, Hidalgo County, TX, 9 Aug.–2 Sept. 2000

Board orientation[a]	Mean (± SE) no. boll weevils (± SE) trapped/48 h[b]
Perpendicular	214.1 ± 22.3a
Parallel	176.9 ± 17.8a
Leeward[c]	146.3 ± 15.6a
Windward[c]	69.2 ± 8.0b
Brush[d]	230.8 ± 16.8a
No brush	153.8 ± 21.4b

[a] For comparisons involving perpendicular, parallel, windward, and leeward orientations, $n = 24$; for positions proximate (≤5 m) to brush, $n = 26$; for positions not proximate (≥ 25 m) to brush, $n = 22$.
[b] Numbers followed by different letters within each of the three separate trap orientation comparisons indicate significant differences ($P \leq 0.05$), Tukey's test.
[c] Traps were perpendicular to wind direction.
[d] "Brush" is considered to be natural perennial vegetation, sugarcane, and citrus orchards; "no brush" refers to highway, fallow field, and canals without perennial vegetation.

Multiple Board Field Test. Repeated measures analysis detected significant treatment (multiple- versus single-pairs of traps) effects ($F = 91.77$, df = 1,136, $P < 0.0001$) and time effects ($F = 11.82$, df = 16,136, $P < 0.0001$) (Fig. 4). Mean trap captures were generally higher in the single pairs of traps than in the multiple pairs of traps at each sampling date. No interaction between treatment and time effects was detected.

The line of best fit for each field operation-associated data set in both multiple and single trap pairs was quadratic ($y = a + b_1{*}time + b_2{*}time^2$). The stalk-pulling-associated peak was significantly higher ($F = 11.08$, df = 2,12, $P = 0.0019$), in the single trap pairs,

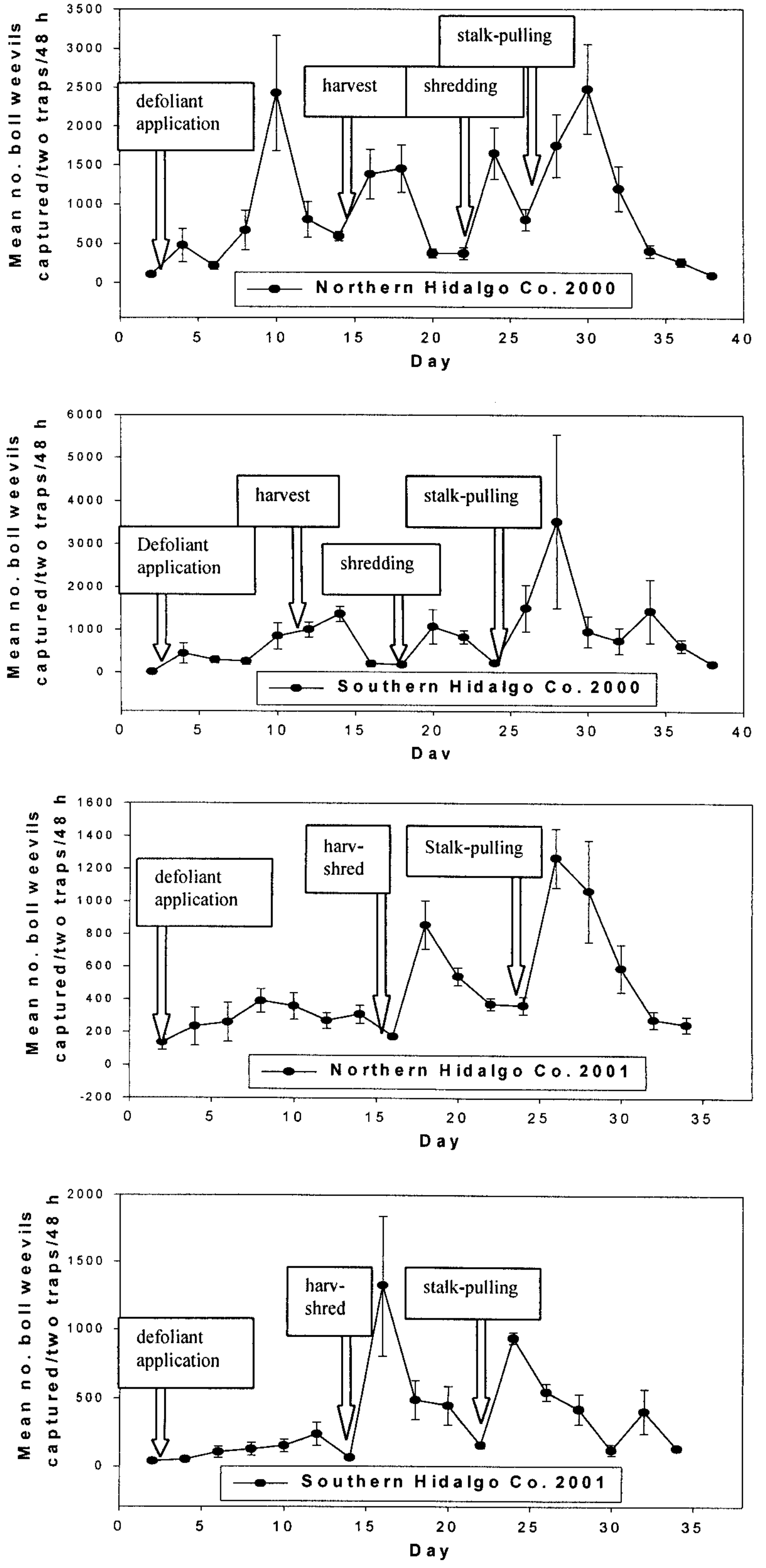

Fig. 3. Mean numbers (±SE) of adult boll weevils captured by board traps during and after routine late season field operations, north and south Hidalgo County, TX, 2000 and 2001 ($n = 6$).

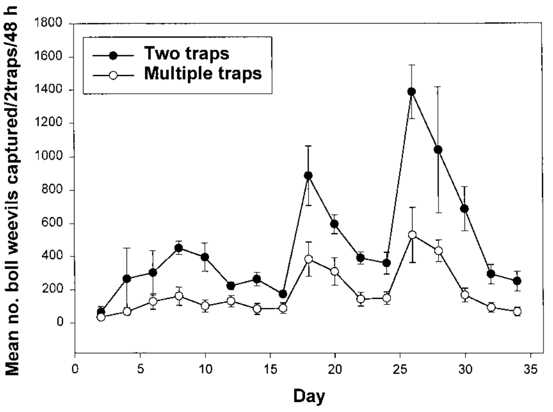

Fig. 4. Mean numbers (±SE) of adult boll weevils collected by board traps deployed as single or multiple-pairs during and after routine late season field operations, northern and southern Hidalgo County, TX, 2001 ($n = 5$).

but no operation-associated peak was significantly different than the others in the multiple trap pairs, nor were there significant treatment effects on slopes. Mean percentage of variation in trap captures was higher at most sampling times in the single-pairs than in the multiple-pairs (Table 3). As an example, the defoliation-associated peak on day 8 was 2.8 times higher on the single-pair traps than on the multiple-pair traps ($t = 4.22$, df = 1,8, $P = 0.0029$). The harvest-shredding-associated peak on day 18 was 2.3 times higher in the single-pair traps than in the multiple-pair traps ($t = 2.45$, df = 1,8, $P = 0.040$), and the stalk-pulling-associated peak on day 26 was 2.6 times higher ($t = 3.70$, df = 1,8, $P = 0.0061$).

The single-pair traps collected an average of 8,008.8 ± 800.2 boll weevils during the 34-d study period, 2.7 times more than the 2,951.0 ± 569.7 boll weevils collected in the multiple-pair traps ($t = 5.15$, df = 1,8, $P = 0.0009$). However, the entire 20-board set of each multiple-pairs treatment averaged 32,322 ± 8,078 boll weevils over the same period, four times higher than collected in the single-pair traps ($t = 3.02$, df = 1,8, $P = 0.0382$).

Discussion

Trap Design Comparisons. All of the traps were equally effective at monitoring low boll weevil populations during the early season. Increased adhesive surface area was associated with greater boll weevil captures during routine late-season field operations when populations were higher and competition of the pheromone lure with volatiles of living cotton plants was reduced. The significant interactions between trap and date effects were probably caused by variation in the numbers of captured boll weevils associated with routine late-season field operations in nearby cotton fields. The board was preferable to the 7.6-cm pipe and the smaller diameter pipes because its >60% larger surface area caught at least 41% ($P \leq 0.0001$) more boll weevils, handling and transporting the boards with adhesive was easiest, the boards could be laid across a flat surface for counting boll weevils, and applying and removing the adhesive (with a flat metal spatula) was simpler than cylindrical surfaces. In the cages, the boards collected boll weevils 2.1 times faster than the Hercon trap, reflected by the significant treatment*time interaction. In the field, nil or low captures by Hercon traps when board trap captures were high have resulted from blockage of the inverted wire mesh cone by spiderwebs, or living or dead boll weevils.

Boll weevils can fly past the Hercon trap and lose their olfactory connection to the pheromone plume, and the trap's construction forces the boll weevil to make a 90° upward turn to enter the bottom of the trap through four holes on the trap's floor. Then the boll weevil must move upward in an inverted wire mesh cone through a ≈4-mm-diameter hole in the apex to enter the 85-ml plastic trap cap. In this study, 757.0 ± 10.75 ($n = 10$) boll weevils blocked the hole, 1,291.5 ± 24.74 ($n = 10$) filled the cap. In contrast, the board trap had a comparatively large, easily accessible surface area designed to capture boll weevils immediately upon contact. Assuming that 1 cm^2 on a board can trap five boll weevils then a board can conceivably catch ≈27,800 boll weevils, ≈37 times and ≈22 times more than the numbers of boll weevils that cover the orifice

Table 3. Differences in mean (± SE) percentage variation between pre-operation boll weevil trap captures and post-operation trap captures in single-pairs of traps and multiple-pairs of traps, Hildago County, TX, 2001

Treatment[a]	Field operation	Mean (± SE) percentage variation[b]					
		Day 4	Day 6	Day 8	Day 10	Day 12	Day 14
Single-pairs	Defoliation	58.9 ± 15.7*	63.5 ± 17.5*	83.6 ± 8.4*	82.6 ± 7.3*	73.8 ± 11.3*	78.2 ± 9.3*
	Harv-shred[c]	76.8 ± 5.2*	68.8 ± 3.0*	52.1 ± 9.6*	57.7 ± 10.5*		
	Stalk-pulling	71.0 ± 8.1*	49.4 ± 15.1*	55.6 ± 10.9*			
Multiple-pairs	Defoliation	48.5 ± 12.4*	72.1 ± 8.4*	72.0 ± 10.3*	59.5 ± 14.4*	70.0 ± 14.0*	51.6 ± 16.7*
	Harv-shred[c]	74.0 ± 6.3*	63.1 ± 11.1*	36.6 ± 6.4*	40.8 ± 10.4*		
	Stalk-pulling	54.5 ± 3.8*	66.4 ± 4.3*	26.2 ± 10.9*			

[a] Single pairs of board traps, one board on the windward edges and one board on the leeward edges of each of five cotton fields and 250 m away from any other traps on the same edges of the fields; multiple-pairs, 10 board traps 15.24 m apart along each leeward and windward edge of five northern Hidalgo County cotton fields.

[b] Percentage variation in numbers of captured boll weevils at each sampling time before a field operation and the numbers of boll weevils caught per 48-h sampling time. Percentages were arcsine-square root transformed before analyses, but untransformed means are presented. * means within each row are significantly different ($P \leq 0.05$) from zero, Dunnett's test.

[c] Harvest and shredding were conducted within 48 h of each other so they are being considered as a single operation.

of the Hercon trap's inverted cone, and to fill the catchment cap, respectively. The highest number of boll weevils captured on a board trap in 48 h during this study was 9,268 on 18 July 2000. Beerwinkle et al. (1996) and Parajulee and Slosser (2001) used Hercon traps to characterize late-season adult boll weevil populations, but the highest population peaks they reported did not exceed 800 boll weevils; this trap-catch ceiling is likely because weevils blocked the inverted cone's orifice. Board traps can show greater, and more accurate, relative adult population differences when the numbers of boll weevil responding to the pheromone lure are high.

Orientation Effects on Board Trap Efficiency. Trap orientation to wind direction did not affect efficiency. However, the greater captures on the leeward side of boards set perpendicular to the wind direction was probably because that side of the board was closest to boll weevils following the pheromone plume to its source. Trap efficiency increased with proximity to brush lines, and other researchers found that trap captures declined after nearby brush lines were removed (Guerra and Garcia 1982).

Routine Late-Season Field Operations Effects on Trap Captures. Chemical defoliation, harvest, shredding, and stalk-pulling each disturbed the boll weevil's primary habitat by induced senescence, mechanical removal of fruiting structures, shredding of stalks, and stalk-pulling. Data collected between field operations and after stalk-pulling conformed to the quadratic model so that the mean percentage variation in trap captures for each field operation were peaks. The consistency of this pattern demonstrates that the various field operations disturb the boll weevil's cotton habitat sufficiently to result in finite upsurges of trapped adults.

Defoliant application involved a tractor moving through the rows of cotton accompanied by foliar coverage with a defoliant toxic to boll weevils (Sappington et al. 2003). Both events represent disturbances to the habitat and resulted in small initial increases in captured boll weevils. Larger numbers of boll weevils were captured four or 5 d after defoliant application when desiccation of the cotton began to occur. Desiccation reduced the weevil's food supply (Montandon et al. 1994), possibly in combination with releases of ethylene from senescing plant material (Parajulee and Slosser 2001), constituted a greater disturbance of the habitat and drew increased numbers of boll weevils into flight for $\approx$7 d. $\approx$10 d elapsed from defoliant application until the associated trap catch peaks subsided.

Although the amplitudes of the various field operation-associated trap capture peaks were not statistically different ($P > 0.05$), the defoliation-associated peaks occurred over more days than the other peaks because the defoliation process required several days to produce its full effect, whereas each of the other operations took place within hours. After the removal of most fruiting structures at harvest, the shredder cut the stalks $\approx$15 cm above the soil surface, the upper portion of the plant was shredded with blades, and the resulting debris was left on the soil surface. The boll weevil trap capture peaks associated with shredding and harvest-shredding indicate that substantial boll weevil populations persisted in cotton fields after harvest in plant material (e.g., bolls on the ground), possibly attracted by ethylene (Parajulee and Slosser 2001) and other volatiles emanating from the cotton stubble and debris. Trap catch peaks after stalk-pulling also showed that large numbers of boll weevils either remained in or returned to the field after the cotton plants had been systematically destroyed by defoliation, harvest, and shredding. The possibility that boll weevils from nearby fields being harvested does not seem to have influenced these findings.

Although defoliation-associated trap captures were mostly lower than those of the other operations, no particular field operation produced statistically different trap catches. However, this study does suggest that variations in defoliation might influence the size of the defoliation-associated peak (i.e., the northern Hidalgo County peak in 2000 was higher than the peaks in southern Hidalgo County and in both locations in 2001).

When not moving between cotton fields and overwintering habitats, the boll weevil is insulated by plant debris in winter (Slosser and Fuchs 1991, Carroll et al. 1993) and within the cotton canopy and fruiting structures during the cotton growing season. Boll weevils move in the spring from overwintering habitats to young squaring cotton (Smith et al. 1965, White and Rummel 1978) in response to the cotton plant volatiles, including ethylene (Duffey and Powell 1979), and aggregation pheromone from boll weevils already in the field (Parajulee and Slosser 2001). After overwintering mortality caused by low temperatures and reduction of food (Parajulee et al. 1996), boll weevil populations are sparse.

The trap data show that during routine late season field operations, boll weevils are still concentrated in and around the cotton fields, and reductions of competing volatiles from living cotton plants increases the efficiency of the pheromone lure. Elimination of the cotton crop causes boll weevils to search for secondary food sources (Guerra 1986, Jones and Coppedge 1999) or overwintering habitats (Parajulee and Slosser 2001), which, by virtue of their movement, presumably increases the likelihood of encountering a trap's pheromone plume to enhance the probability of encounters with pheromone plumes, late-season trap lines will likely need to be deployed at intervals in or around fields.

Effects of Multiple Board Traps. The consistently lower numbers of boll weevils captured on each of the multiple-pair traps versus the single-pair traps showed that placement of board traps at 15.24-m intervals along field edges during late season operations had an impact on adult boll weevil populations moving in response to each field disturbance. Total cumulative numbers of adult boll weevils captured on all 20 of the multiple-pair traps were only four times greater, rather than 10 times greater, than the single-pair traps. However, because the peaks did not become progressively smaller after each successive field operation in the multiple-pairs treatment, the total numbers of boll weevils in the fields might not have been substantially reduced. Further field studies designed to assess the efficiency of large-capacity traps deployed in larger numbers and at closer intervals on the edges and inside late season cotton fields could conceivably affect total numbers. It is also possible that trap efficiency could be enhanced by adding an ethylene source to the pheromone lure (Parajulee and Slosser 2001).

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